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PRELIMINARY ANALYSIS OF U.S. RESIDENTIAL AIR LEAKAGE DATABASE v.2011

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ABSTRACT

Air leakage and other diagnostic measurements are being added to LBNL's Residential Diagnostics Database (ResDB). We describe the sources of data that amount to more than 80,000 blower door measurements. We present summary statistics of selected parameters, such as floor area and year built. We compare the house characteristics of new additions to ResDB with prior data. Distributions of normalized leakage are computed for income-qualified homes that were weatherized, homes that were participants of various residential energy efficiency programs, and new constructions built between 2006 and 2011. Further work is underway to relate air leakage to house characteristics utilizing the full database for predictive modeling of air infiltration and to support studies of energy efficiency. Current status of ResDB can be found at http://resdb.lbl.gov/.

KEYWORDS

Air leakage, blower door, fan pressurization measurements, infiltration

INTRODUCTION

The needs of residential energy efficiency and weatherization programs have led to many measurements of air leakage being made in existing homes and new constructions in recent years. We gathered this data to characterize the air leakage distribution of homes in the US. This effort is necessary to evaluate the energy implications of uncontrolled airflow through the building envelope. It also allows predictions of the expected improvements from various energy efficiency measures, given the baseline of current building stock.

Previous versions of LBNL's Residential Diagnostic Database [1] (ResDB) were dominated by homes from an income-qualified weatherization assistant program in Ohio, and also by homes that were built for the extreme weather in Alaska. Our latest data collection effort not only increased data counts, but also improved spatial representation of the dataset. Data collection is nearly completed at the time when we wrote this conference paper. Because data analysis is on-going, summary statistics and preliminary analyses presented here are likely to be revised when the final report is released.

DATABASE DESCRIPTION

Data Sources

We collected blower door data on over 81,000 homes, of which over 70% are single-family detached homes. Mobile home and multi-family dwellings made up approximately 20% and 10% of the remaining data. Income-qualified weatherization assistant programs (WAPs) remain the major sources of data, accounting for almost 60% of the blower door measurements. The database contains WAPs data from 15 states. Over 95% of the WAPs homes were tested at least twice, once before and once after weatherization. Since WAPs are administrated by local state agencies, there are many differences in how the work was performed and data collected; see [2] for an overview of national evaluation of WAPs. Some data were provided to us by agencies responsible for the programs in the form of a database. Others are contributed by contractors who performed the work. In future analysis, we plan to compare state-by-state or regional differences among WAPs, if any, in reducing air leakage.

Residential energy efficiency programs are another major sources of data. For example, the Home Performance with Energy Star program is implemented in over 30 states in US [3]. Many utility sponsored programs also offer incentives for energy efficiency upgrades. The majority of the energy efficiency programs data were contributed by energy auditors who performed the work. Some energy efficiency programs that contributed data provided pre- and post-retrofit blower door measurements, which are available in about 60% of the data.

We defined new construction entries as those built 2006 and later, i.e. after the release date of the prior ResDB. New constructions account for approximately 20% of the data in the current database. Many of the new constructions were tested for air leakage in order to obtain an energy certification. These data were contributed mostly by energy auditors who performed the tests or by verification organizations. In addition, there are also a few research programs that collected data on new homes, such as Department of Energy's Building America Program [4]. California, North Carolina, Nevada, Texas, and Washington are the states with the most new construction data available in the current ResDB.

Data Summary

New data being added to ResDB are mostly single-point blower door measurements at 50 Pa. These measurements were converted to normalized leakage (*NL*) assuming a power law flow exponent of 0.65 as follows:

$$NL = 1000\left(\frac{ELA_{4\text{ Pa}}}{Area}\right)\left(\frac{H}{2.5\text{ m}}\right)^{0.3} \quad \text{where} \quad ELA_{4\text{ Pa}} = \sqrt{\frac{\rho}{2\times 4\text{ Pa}}}\left(Q_{50\text{ Pa}}\right)\left(\frac{4\text{ Pa}}{50\text{ Pa}}\right)^{0.65} \tag{1}$$

$ELA_{4\text{ Pa}}$ (m^2) is the effective leakage area at 4 Pa, *Area* (m^2) is the dwelling floor area, *H* (m) is the dwelling height, ρ = 1.2 kg/m^3, and $Q_{50\text{ Pa}}$ (m^3/s) is the airflow rate at 50 Pa measured by the blower door. In some cases, data contributors reported other measures of air leakage, such as specific leakage area, which is *ELA* normalized by floor area. All data were converted to normalized leakage for the analysis.

Dwelling locations (state, county, city, or zip code) are known for all data but at varying levels of detail. Figure 1 shows the spatial distribution of single-family detached homes roughly mapped to 19 climate zones [3] by state-line. The number of data shown, *N*, exclude entries that are known to be mobile homes and multi-family homes (note that as we continue to check ResDB for errors and missing data, some entries might be reclassified). Figure 1 shows that most of the climate zones are represented in ResDB v2011, including populous areas in US, such as the Northeast states (NY-PA-NJ), Florida (FL), Texas (TX), and California (CA). Kentucky and the South remain two areas that we lack data.

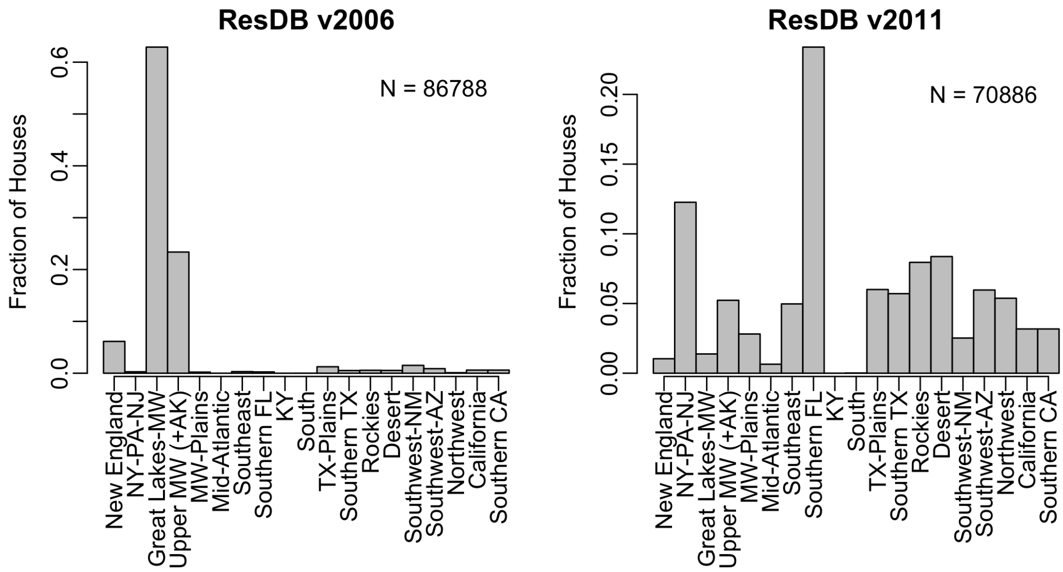

Figure 1. Single-family homes in prior (v2006) and current (v2011) ResDB organized by climate zones. Many climate zones cross state-line [3], but for simplicity this is not reflected here because the data is segregated by state-line. This is acceptable for most climate zones except for CA and TX. For these two states, the data counts are split equally between two zones: TX-Plains and Southern TX, California and Southern-CA, respectively.

Other parameters available in ResDB include, in descending order of availability, dwelling size (floor area, height, number of story, volume), foundation type, duct system, number of bedrooms and occupants. Compared to the prior version, the current ResDB contains more information about the heating, cooling, and ventilation system. There are approximately 30,000 duct blaster data entered into ResDB that were measured using different test configurations, e.g. leakage to outside, supply air leakage to outside, total leakage, etc. Combustion test data, indoor air contaminants measurements, and energy usage or projected savings are also available in a few datasets. We use a SQL database management system for data entry, storage, and retrieval. This software program allows us to better organize the multi-dimensional datasets for analysis.

EXPLORATORY ANALSYSIS

Houses Characteristics

Figure 3 compares the basic house characteristics represented in the prior (v2006) and current (v2011) version of ResDB. Data that falls outside of the acceptable ranges are excluded from the comparison. Acceptable ranges are defined as floor area between 30 and 1000 m^2, number of stories between 1 to 3, year built between 1800 and 2011, and house age at the time of testing is non-negative. About 2600 data points were excluded based on these criteria.

New additions to the current ResDB tend to be larger in floor area, which is reflective of the trend of US homes being built [5]. In ResDB v2006, houses with floor area <92 m^2 (1000 ft^2) were assumed to be single-story, and larger homes were assumed to be one and a half story. For the purpose of computing *NL* (Equation (1)), this is not a large source of uncertainty [6] even though two-story dwellings are more common in the US than split-level, as shown by v2011 data in Figure 2. There are comparable proportion of one- and two-story homes in both versions of ResDB, assuming that many of the previously classified one and a half story homes are more likely to be two-story homes.

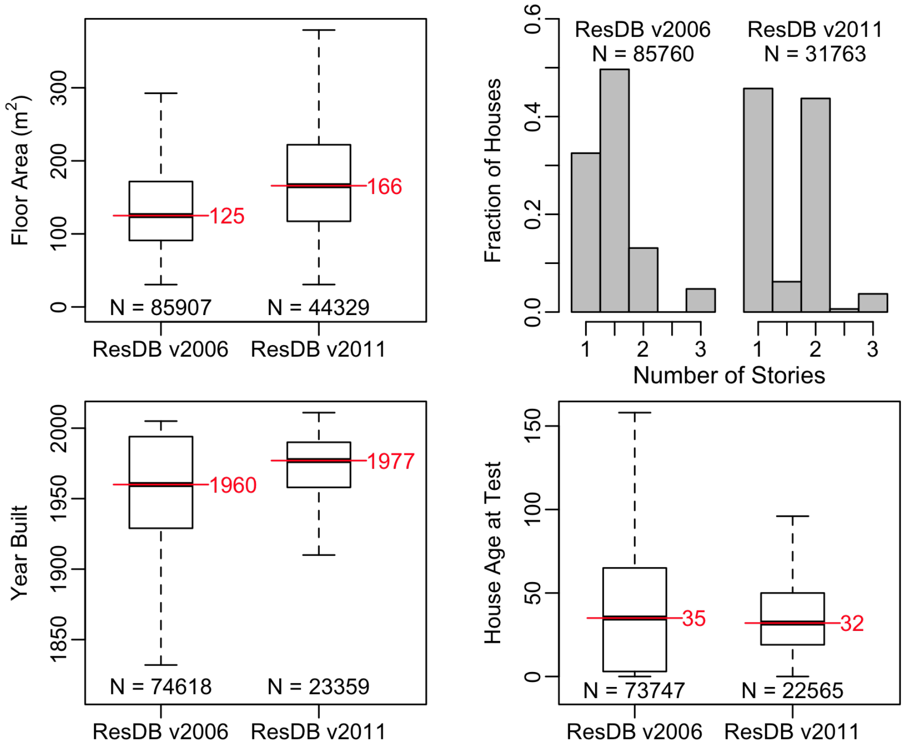

Figure 2. Comparison of house characteristics of new data added to v2011 ResDB with data in v2006. Boxplot shows the range where the central 50% of the data are between the 1st and 3rd quartiles. Extreme values beyond extent of the whiskers are not shown. Median floor area, year built, and house age at test are highlighted in red.

There are many data with missing year built in the new data that are added to ResDB v2011. Since year built is a predictor for air leakage [1], we are in the process of seeking this information if available from data contributors or estimating the values via other means, such as real estate listings and records. Overall, the homes that are added to ResDB v2011 are about the same age as those in v2006 at the time when the blower door tests were performed (Figure 2). The boxplot also shows that homes added to ResDB v2011 are more similar in age as a group, as indicated by a narrower distribution, relative to data in v2006.

Despite the similarity in house age, there is a difference in the year built of homes. First, v2006 does not contain the new constructions built between 2006 and 2011. ResDB v2006 is also the cumulative result of many years of data compilation since 1990, whereas most of the new additions to v2011 were blower door tests performed in the past few years. The combined dataset will allow us to evaluate if new constructions built today are more airtight than homes that were built in the 1980's and 1990's when those homes were tested as new. We also plan to separately assess the relationship of air leakage with year built and house age, if possible, with the combined dataset. For example, new constructions today may become more leaky with age at a different rate than homes that were built in the 1980's and 1990's.

Normalized Leakage

Normalized leakage was computed using all valid blower door measurements. We erred on the inclusive side to estimate floor area and house height, the two parameters necessary for computing $ELA_{4\ \mathrm{Pa}}$, using all available means, such as by inferring from house volume and number of story. We also included blower door measurements that were performed at pressure differential other than 50 Pa, typically between 25 and 50 Pa. Some of these are multi-point blower door tests that measured airflow at different pressure differentials, but there are also single-point measurements where the target pressure of 50 Pa was not reached. If provided, we used the reported flow exponent instead of the 0.65 default value. Approximately 1000 flow exponent estimates are available in ResDB v2011. Most values (90%) fall between 0.58 and 0.78.

Figure 3 shows the resulted *NL* having a distribution that is roughly lognormal with a geometric mean of 0.51 and a geometric standard deviation of 1.98. This distribution includes all valid *NL* estimates, so some homes were represented more than once if multiple blower door measurements were performed. This distribution also has <u>not</u> been adjusted for the house characteristics, so it should not be considered as representative but rather, a preview of the air leakage measurements in ResDB v2011.

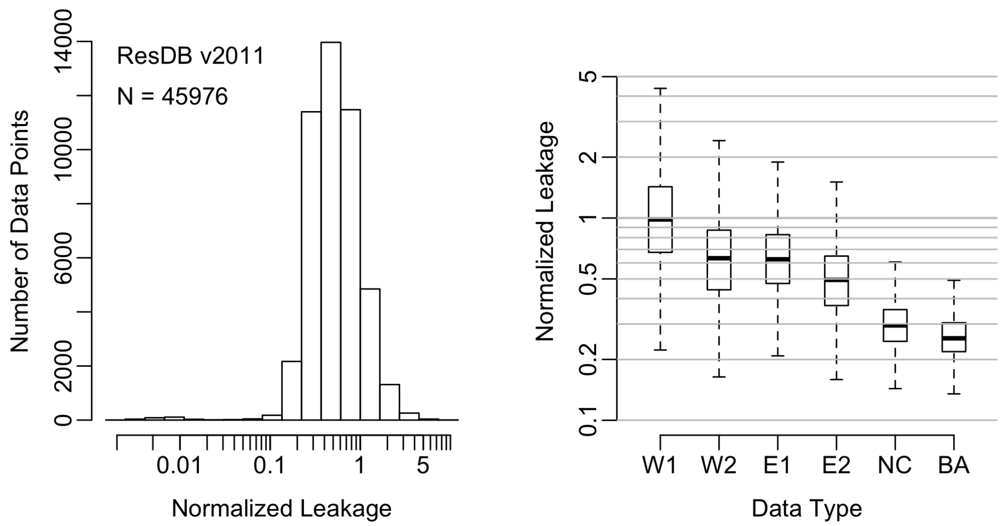

Figure 3. Unadjusted normalized leakage distribution computed from blower door measurements in ResDB v2011 (left panel). The right panel shows differences between the unadjusted *NL* distributions when estimates of *NL* are categorized into six types according to the source of data (see Table 1 for data type descriptions).

	Data Type	Normalized Leakage	Number of Data	Floor area (m^2)	Year Built	Age
	Income-Qualified WAPs					
W1	Pre-weatherization	0.98 (0.68 – 1.43)	6576	118	1962	34
W2	Post-weatherization	0.63 (0.44 – 0.87)		(91 – 166)	(1928 – 1977)	(50 – 83)
	Energy efficiency program					
E1	Pre-retrofit	0.63 (0.47 – 0.83)	8225	190	1980	30
E2	Post-retrofit	0.49 (0.37 – 0.65)		(146 – 248)	(1960 – 2008)	(9 – 50)
NC	New constructions	0.29 (0.25 – 0.35)	9745	199 (162 – 260)	2008 (2007 – 2008)	1 (1 – 2)
BA	Building America Program	0.25 (0.22 – 0.30)	724	178 (141 – 223)	2008 (2008 – 2008)	1 (1 – 2)

Table 1. Summary statistics of the unadjusted normalized leakage and corresponding house characteristics. Median values are shown with the 1st and 3rd quartile values in parentheses.

As previously observed in ResDB v2006, income-qualified WAPs homes tend to be the most leaky. This is partially because they tend to be older and smaller in size compare to other homes, but also potentially because of disrepair of the building structure. The difference in median *NL* between pre- and post-weatherization is about 35%. This reduction is slightly more substantial than the apparent change from retrofits performed on homes that participated in the various residential energy efficiency programs, where the change in median *NL* is about 22%. There are many possible explanations for this, some of which can be investigated by comparing the before and after *NL* by first adjusting for parameters that have a known effect on air leakage. For example, a comparison can be made between WAPs and energy efficiency programs by selecting only homes that have similar characteristics and from the same state.

New constructions built in 2006 and after have a median *NL* of 0.3. This value approaches the median *NL* from the Building America research program, which has the goal to accelerate the development and adoption of building energy technologies in new residential construction. In addition, the range of *NL* values are similar among the ResDB new constructions and Building America data. The factor of three differences in *NL* from about 0.15 to 0.5, as shown in Figure 3, is likely a reasonable estimate of the inherent differences among new homes.

CONCLUSION

Large number of blower door and other diagnostic measurements have been added to LBNL's ResDB. We preformed exploratory analyses to look for relationships between normalized leakage and house characteristics such as floor area, year built, and if the house tested is part of an energy efficiency or income-qualified weatherization program. Findings are compared with previous published analyses of ResDB. Once the current data has been checked for quality it will be combined with v2006, and the full ResDB v2011 will be analyzed to characterized the stock of US housing. Such analyses will support studies of energy efficiency and related concerns such as indoor air quality.

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